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TESTING OF IMMERSION HEATERS FOR IN-TANK SOLIDIFICATION CIRCULATORS

By

J. Dunn

Chemical Development Section
Chemistry Department

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PACIFIC NORTHWEST LABORATORY
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TESTING OF IMMERSION HEATERS FOR IN-TANK SOLIDIFICATION CIRCULATORS

INTRODUCTION

During the development of the present in-tank solidification prototype, it was recognized that potential cost savings might be achieved by using direct immersion electric heaters. With heat applied directly to the waste solution, the volume of air supplied to the system is determined by the amount needed to maintain circulation in the tank. With the present heated air evaporator unit, substantially larger volumes are required, as determined by the thermal capacity of the air. In the initial prototype 5000 scfm of air is provided; circulation requirements are estimated at 200 scfm. For the higher heat inputs planned in subsequent units, air volumes would increase approximately in direct proportion to heat rating. The escalation in system cost is much more pronounced than would be expected by an arithmetical extension of the power requirements since not only does the cost of the blowers increase, but all other associated equipment becomes progressively more expensive. Motors would be larger as would condensers installed in the off-gas system. The required work and exhaust blowers would be bigger, and more cooling water required. The load on the waste water system would increase, possibly necessitating construction of additional cribs.

The major technical concern with direct immersion heating concept is the possible scaling of the heat transfer surfaces, leading to excessive element temperatures and premature heater failures. For any given waste composition, the scaling effect would be expected to be a strong function of surface heat flux and fluid velocity.

This report presents the results of preliminary bench- and semiworks-scale tests performed to evaluate the immersion heater concept. Design parameters for a prototype circulator are also discussed.

SUMMARY

The use of direct immersion electric heaters is proposed for concentrating intermediate level wastes in underground tanks. A series of tests has been completed to investigate the major technical concern with this concept (that of scale deposition on the heat transfer surfaces). Tests were performed with simulated coating wastes, concentrated up to four times the original volume, and containing either 0 or 1% added sodium sulfate or phosphate. Power density of the heaters ranged from 17 to 500 W/in.^{2}. No scale deposition on heated surfaces occurred in either bench- or pilot-scale tests during any of the tests; maximum test duration was approximately 2600 hr. Some solids buildup occurred on heater supports in the vapor space above the heaters during early stages of the test program. This problem was overcome by relocating the reflux return line to provide a washing action, and the deposit proved readily soluble in water. Periodic washes would be expected to minimize solids formation, which otherwise might occur with either the immersion heater or hot air system.

Based on the heater performance and on the absence of scale on the heated surfaces, an electric heater prototype is recommended for testing under plant conditions.

DESCRIPTION OF EQUIPMENT

A. Bench Scale

Figure 1 illustrates the equipment used for testing of immersion heaters in wastes of various composition. Each

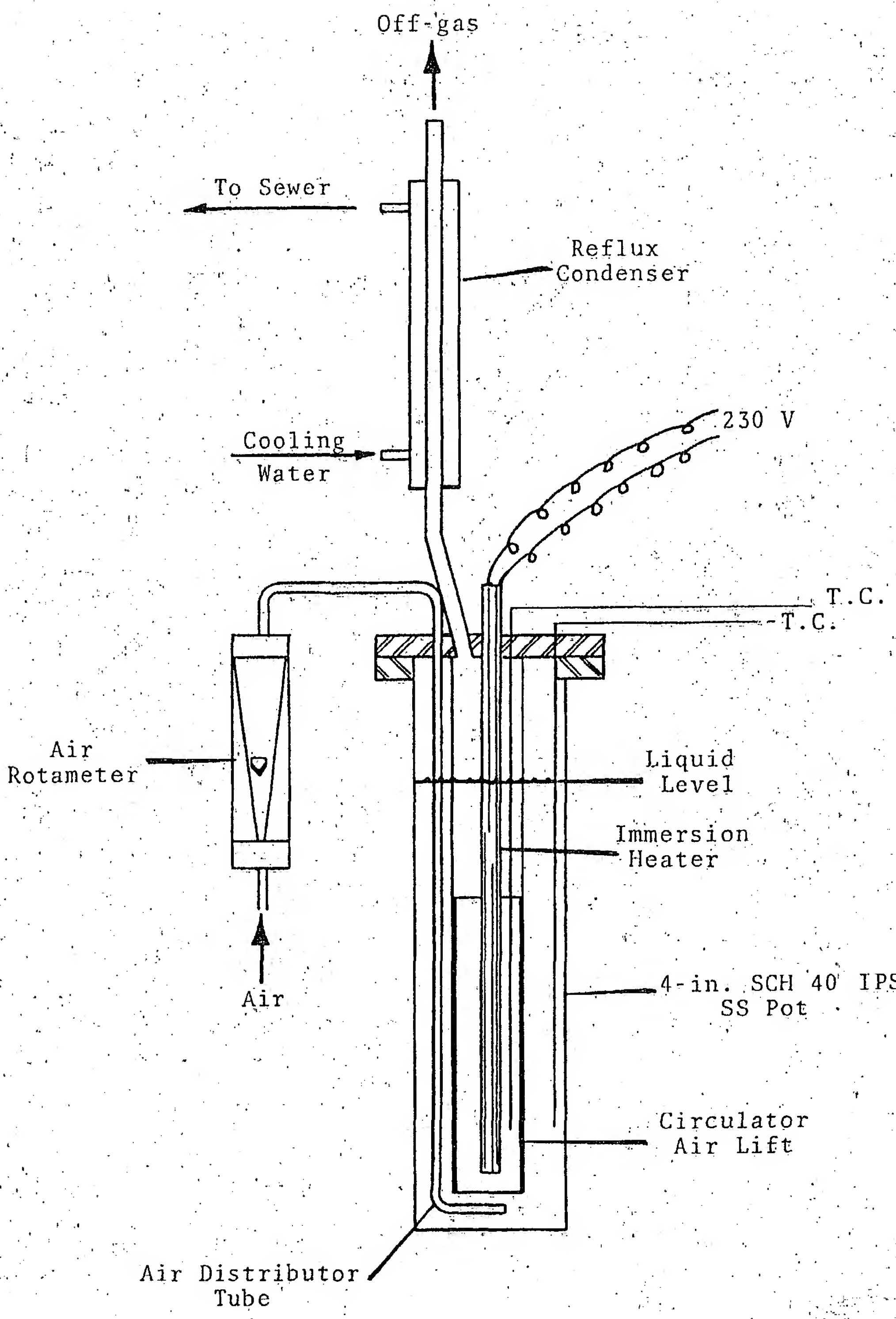

FIGURE 1

Immersion Heater Test Stand

4-in.-diam stainless steel vessel contains a circulator centrally suspended from the cover. The element being tested is mounted within the circulator so that the heated portion is always below the surface of the liquid waste. Air metered to the bottom of the circulator tube creates an air-lift pumping action and moves liquid upward past the heater sheath. A water-cooled, reflux condenser mounted at the top of the test stand returns condensate to the body of the waste within the vessel. The occasional addition of water is required to maintain a constant liquid level, i.e., a constant composition for equilibrium. The heaters employed in these tests were stainless steel clad 230 V cartridge type immersion heaters with a power rating of 80 $W/in.^2$.

B. Semiworks Scale

The test stand for evaluation of alternative heater designs is shown in Figure 2. This stand is a 55 gal stainless steel drum used as the process vessel with one centrally located circulator suspended from the lid. This circulator is a section of nominal 2-in.-diam steel pipe approximately 2 ft long. It is suspended by steel rods from the top of the tank so that the lower end of the circulator is about 3 in. above the floor of the vessel. An air distributor discharges a metered supply of air into the bottom of the circulator, creating an air-lift which circulates liquid past the electrical heaters suspended within the circulator. The heaters generate a thermal siphon effect which adds to the air-lift circulation of liquid. A tubular heat exchanger or water-cooled condenser, located above the vessel, condenses vapors from the off-gas stream and returns the condensate to the bulk liquid. Visual observation of the internal action and operation is possible through sight glasses mounted in tank top nozzles. Temperatures in the bulk liquid

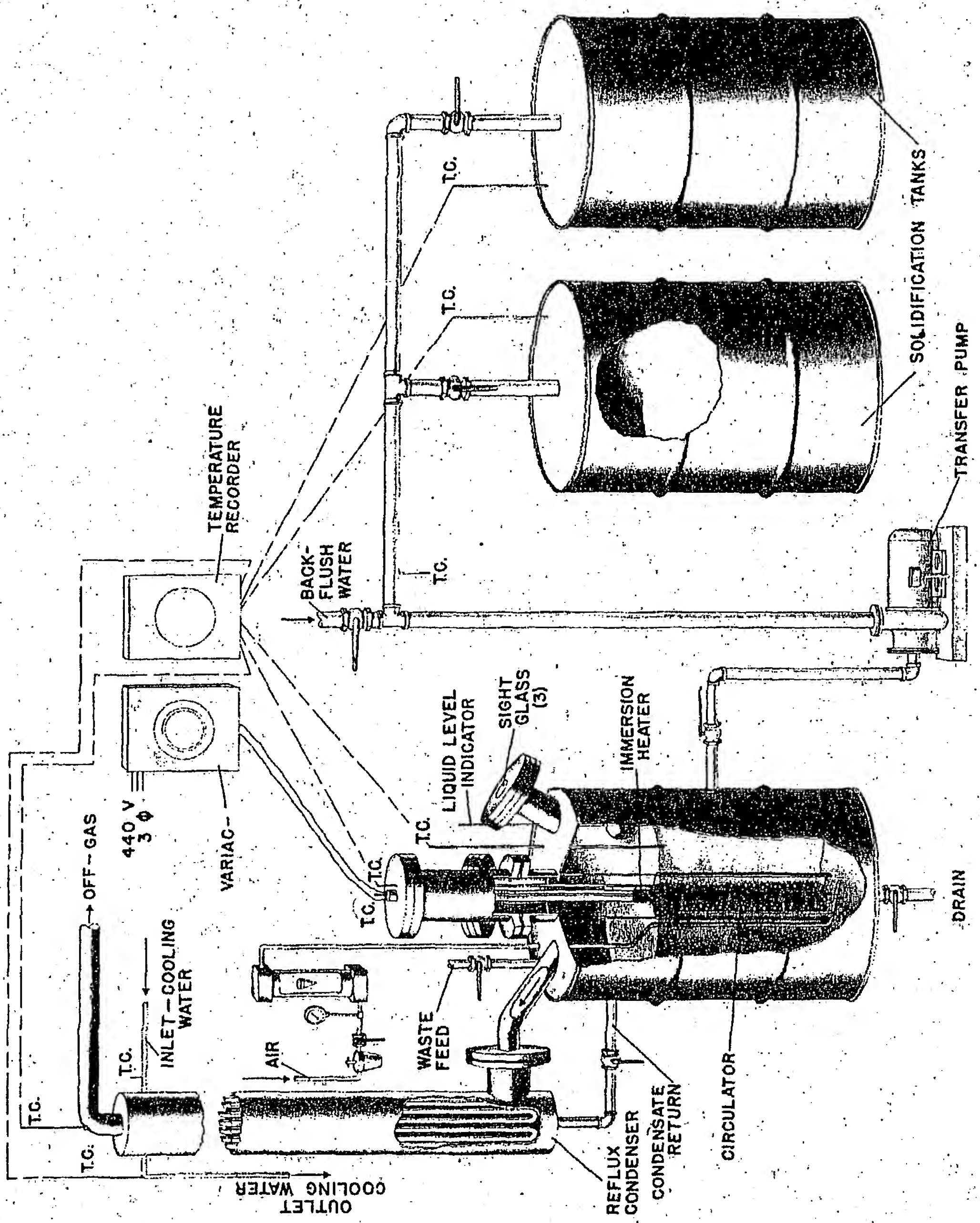

FIGURE 2

Waste Concentration Immersion Heater Demonstration

and in the circulator are measured by thermocouples. The solution composition and desired liquid levels are maintained by the addition of precalculated amounts of dilute feed and/or water. Additions are made periodically to replace moisture carried away in the off-gas.

OPERATION

A. Bench Scale

Four circulator-evaporator test stands were employed to study possible adverse effects of retrograde solubilities of extraneous components of waste streams. The first solution tested was dilute coating waste with the following composition:

1.61M $NaOH$
1.10M $NaNO_2$
1.00M $NaNO_3$
1.36M $NaAlO_2$
0.04M Na_2SiO_3

All of the remaining tests employed the above constituents but with varying concentrations and with additives. The second test was conducted with coating waste concentrated by a factor of two. Tests three and four were concentrated by a factor of four. One weight percent of trisodium phosphate was added in test three and 1 wt% of Na_2SO_4 in test four. The solution levels were established and maintained between 2 and 4 in. above the top of the centrally mounted circulators (and the same distance above the heated section of each heater). A nominal air flow of 0.25 scfm, admitted to the bottom of each circulator, generated a liquid recirculation rate of approximately 2 gal/min. This was enough to cause a complete turnover of tank contents about once a minute. Periodic inspections were made to detect and measure scale formation.

Figure 3 shows coating waste, concentrated by a factor of four after it has solidified on cooling to room temperature.

B. Semiworks Scale

Coating waste, obtained from the dissolution of aluminum jackets from unirradiated reactor fuels, was employed in testing of the two-foot long heaters. The composition given for bench scale testing is identical with that used in these tests. In appearance, the waste is opaque, gray, viscous, light, and milky slurry containing occasional chunks of precipitated solids. Constant agitation and heating are necessary to maintain fluidity and prevent formation of a solids cake in the storage vessel. The waste, with a sp. gr. of 1.2, was charged to the concentrator to a depth of 6 in. above the top of the circulator and the heated portion of the immersion heaters. Air flow was started to generate pumping action at a rate of 2 gal/min, and the electrical power was turned on. Fresh additions of coating waste were made at intervals to maintain the liquid level until the original concentration had been increased by a factor of four. At this point, the cooling water to the reflux condenser was turned on and equilibrium conditions were maintained for the remainder of life testing. Tap water was added to replace moisture lost through the off-gas. The circulation pump installed in the test tank was operated throughout the test to demonstrate pumpability of the slurry at all concentrations. Periodic inspections were made for malfunctioning or scale deposition.

RESULTS

A. Bench Scale Heaters

Operation of the heaters was uneventful from the process standpoint or deposition of scale from all solutions. The heated

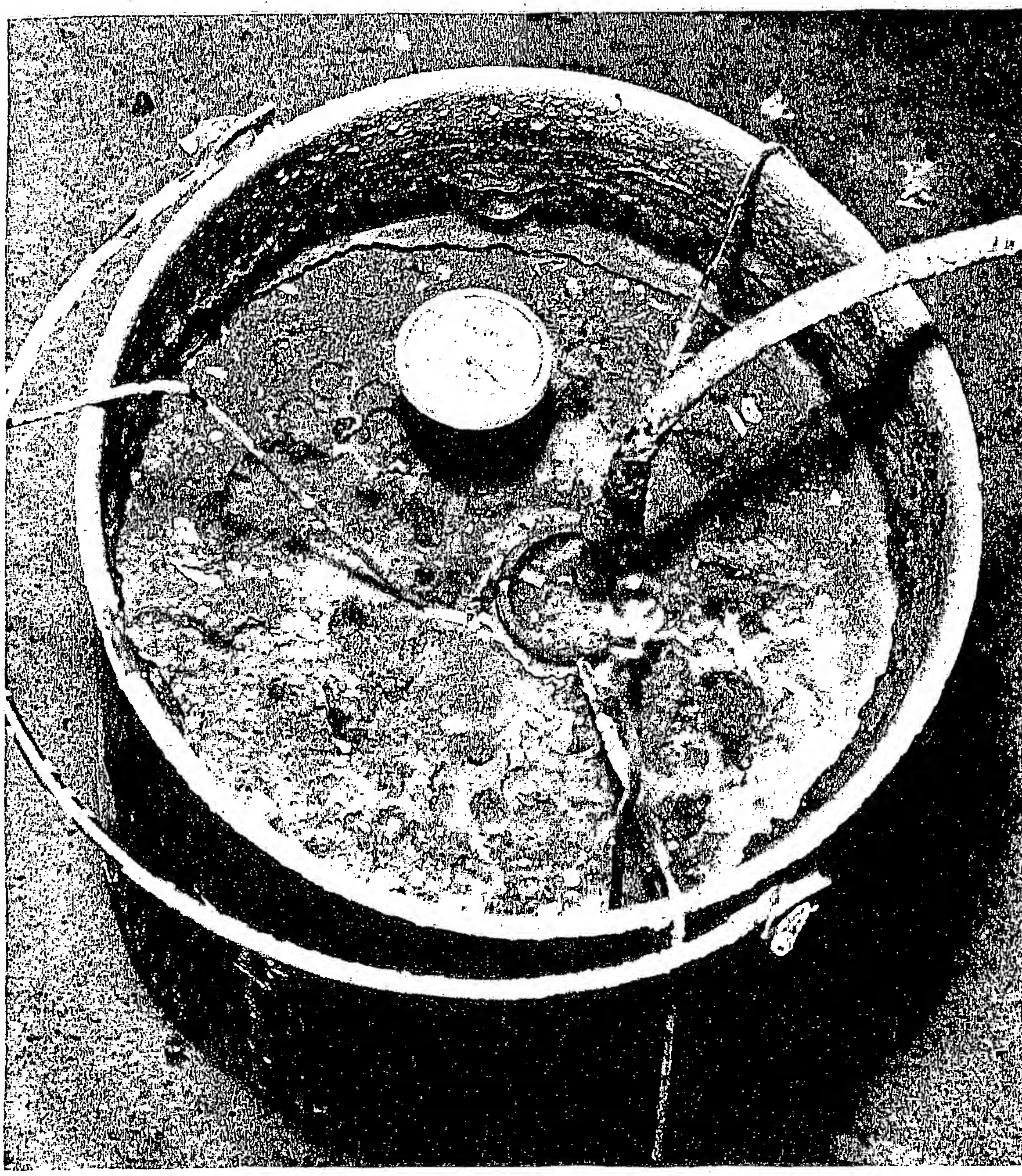

FIGURE 3

Solidified Coating Waste

portions of the cartridge units remained free from scale and showed no corrosion after 1904 hr of operation. During this time, the maximum solution temperature attained was 110 °C. Some difficulties were experienced in preventing splashing of the solution during additions of feed or water, and several times, the splashed liquid caused electrical shortcircuiting of the heater leads.

B. Semiworks Scale

Operation was smooth and uneventful during the early part of life testing. Two heaters were tested simultaneously in the same circulator. On the first test, a 17 W/in.^{2}, 600V heater was tested together with a 40 W/in.^{2}, 230 V heater of different manufacture. After 18 days, a solidified mass was observed on the unheated portion of the heaters. Splashing and seething of the hot liquid with associated evaporation into the vapor space caused a buildup of solids on the heater supports. The condensate return line was rerouted to bathe the upper parts of the heaters and keep them free of solids. This change prevented further deposition for the remainder of the test. After 1440 hr electrical failure of the 17 W/in.^{2}, 600 V heater interrupted operation. The difficulty was traced to corrosion of the stainless steel sheath at the juncture of the heated and cold portions. A solids buildup at this point, while not massive, was sufficient to entrap NaOH. As the solids impaired heat dissipation, the retained heat melted the NaOH. The molten caustic then rapidly attacked the stainless sheath and finally complete penetration resulted with subsequent shortcircuiting and burnout of the electrical components. This particular heater was found to be receiving less than adequate condensate flush. The companion heater which was washed by the bulk of the fluid return was unattacked.

Operation of the second pair of immersion heaters was completely satisfactory during the same 1440 hr period. No scaling, abrasion or corrosion was noted even after the solution had been concentrated by a factor of 6.9.

Buildup of the solids mass is attributed to circulator design rather than to inadequacy of the heater. The use of condensate from the reflux, steam or periodic water sprays should prevent the recurrence of this type of trouble. The use of inconel as a sheath material is expected to promote heater longevity. It has approximately 10-fold greater resistance to caustic attack than stainless steel.

C. General

Table 1 lists pertinent specifications and data obtained in both the bench scale and the semiworks scale tests. No obvious advantages or disadvantages traceable to voltage or current density have been observed.

FUTURE WORK

It is deemed necessary, or at least desirable, to conduct further testing as actual in-plant tests on prototype or partial size equipment. Problems of air flow, fluid flow, solution composition, heat transfer rates, temperature increase rates in the surrounding fluid, solids occurence and deposition, mechanical shock and stability, are seen as regulatory influences. The construction of similar geometries is difficult for the resolution of more than one or two questions in any given model. Hence, it is felt that better and more economical answers to more questions can be obtained in shorter time by construction of a scaled model of from 100 to 500 kW capacity installed in one of the actual underground storage tanks.

TABLE I

SUMMARY OF ELECTRICAL IMMERSION HEATER OPERATION

Bench Scale Tests

(All heaters Watlow Firerods, 80 W/in.^{2}, 230 V)

Heater	Solution	Hours Operated	Remarks
1	Coating Waste, dilute	41	Leads shorted by moisture
2	Coating Waste, concentrated 2 X	176	Leads shorted by moisture
3	Coating Waste, dilute	147	Leads shorted by moisture
4	Coating Waste concentrated 2 X	1904	No scale, trouble free
5	Coating Waste concentrated 4 X plus 1% Na_3PO_4	1904	No scale, trouble free
6	Coating Waste, concentrated 4 X plus 1% Na_2SO_4	1904	No scale, trouble free

Semiworks Scale Tests

Heater	Solution	Hours Operated	Remarks
1	Coating Waste, concentrated 4 X	2627	No scale, trouble free
2	Coating Waste, concentrated 4 X	2627	No scale, trouble free
3	Coating Waste, concentrated 4 X	268	Burned out, circulator plugged
4	Coating Waste, concentrated 4 X	1440	Sheath corroded by molten caustic
5	Coating Waste, concentrated 4 X	1708	No scale, trouble free

Heater 1	Watlow Firerod,	67 W/in.^{2},	230 V
Heater 2	Watlow Firerod,	246 W/in.^{2},	230 V
Heater 3	Watlow Firerod,	500 W/in.^{2},	440 V
Heater 4	Vulcan,	17 W/in.^{2},	600 V
Heater 5	Chromalox,	40 W/in.^{2},	230 V

Preliminary calculations extrapolated from design data[1] indicate air requirements of 200 ft^3/min to circulate water 10,000 gal/min in a 40-in.-diam circulator. Viscosity and density differences of the waste solutions will vary during the concentration process and from tank to tank as chemical composition varies. To accommodate the physical bulk of the heater elements and supports in a circulator compatible with the existing 42-in.-diam tank nozzle and remote installation techniques, a unit should be 40 in. in diameter. The cross-sectional area occupied by the heaters and supports should occupy not more than 10% of the pipe area (or 123 $in.^2$). Air, supplied at 250 scfm, should then generate a nominal liquid flow rate of 10,000 gal/min.

Final design parameters will be dependent upon prototype success in actual plant conditions.

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(1) M. W. Cook and E. D. Waters. Operational Characteristics of Submerged Gas-Lift Circulators, HW-39432. General Electric Company, Richland, December, 1955.

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